THE *EDISON* INFRARED SPACE OBSERVATORY AND THE STUDY OF EXTRA-SOLAR PLANETARY MATERIAL

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January, 1993

Abstract. *Edison* is a proposed large-aperture, radiatively-cooled space observatory planned to operate at wavelengths between 2 and 130 μm or longer. Current estimates for the telescope allow an aperture of 1.7 m which will achieve a final equilibrium temperature of about 30 K, although use of cryo-coolers may permit temperatures below 20 K. *Edison* will be a powerful tool to investigate our Solar System, as well as planetary material around distant stars. At near- and mid-infrared wavelengths, where planetary material emits most of its radiation, *Edison* will be the most sensitive photometric and spectroscopic observatory under current consideration by the space agencies. With its large aperture, *Edison* will be able both to resolve the structure in nearby circumstellar 'Vega disks" and to discriminate faint IR emission in the crowded environment of the galactic plane. With its long lifetime, *Edison* will allow extensive follow-up observations and increase the likelihood of catching transient events. We propose *Edison* as a precursor to elements of a future space-based IR interferometer.

Key words: infrared - space observatories

1. Background: Infrared Observations of Planetary Material

The search for and study of extra-solar planetary material is one of the most exciting prospects for future infrared space missions. Solids within a few hundred AU of more-or-less normal stars equilibrate at temperatures in the range of **20- 500** K, which means that the bulk of the radiation emitted by planets, comets, asteroids, moons, dust, and other circumstellar material will emerge at wavelengths between about 5 and 200 μm. A number of proposed programs of extra-solar planetary detection and study require distinguishing between the feeble emission from a star and that Of planets. The contrast between the emission from a star and that of planets such as the Earth or Jupiter, although extremely small, is greatest at mid-infrared wavelengths. Finally, although many presentations at this conference emphasize *detection* of planetary material, a great deal more work will be required to analyze and to understand whatever will be found orbiting distant stars. This will require spectroscopic observations of key gaseous and solid state diagnostic features in the infrared.

Edison, with its large aperture, operating at the celestial background limit, will have as part of its key scientific justification, the detailed study of planetary material around other stars.

2. Current Design for the *Edison* Observatory

2.1. Radiative Cooling of Space Observatories

Radiative cooling for infrared space observatories has several advantages over the alternative, cooling via large tanks of liquid cryogens: [1] current designs indicate that for the same overall spacecraft size, a telescope approximately twice the diameter of that of a cryogenic observatory is possible; [2] a radiatively-cooled observatory has no built-in lifetime; [3] without the massive cryogen tanks, the spacecraft is substantially lighter and may be less complex, translating into savings in time and money; and [4] a radiatively-cooled observatory is likely to be more robust on orbit against potential catastrophic failures, such as inadvertent pointing toward one of the many hot objects in our Solar System. These characteristics have been recognized for some years, leading to the design and development of a number of IR/Sub-mm observatories which will be cooled at least in part via radiation: the *Cosmic Background Explorer* (COBE), the *Sub-Millimeter Wave Astronomical Satellite* (SWAS), and the *Far-Infrared Space Telescope* (FIRST).

At the same time, radiative cooling has clear technological hurdles, including the necessity for additional cooling of some elements of the instruments, notably long-wavelength detectors, and the possibility that without the massive cryogen tanks, there may be spatial and/or temporal temperature fluctuations in the optical system.

2.2. Basic Outline of *Edison* Design

Large solid bodies deep in space equilibrate at temperatures in the range of 5 - 15 K, depending upon their composition and their proximity to sources of heat. Such temperatures indicate that, if the radiation environment of deep space can be duplicated for spacecraft, radiative cooling is the future technological direction for infrared and sub-millimeter observatories. The first goal, then, of proper passive cooling requires that the radiation field incident upon the optical system approach as closely as possible that of deep interstellar space.

Hawarden et al. (1992) outline the basic principles of an effective radiatively-cooled space telescope. These have been incorporated into our current design for *Edison*, which is shown in cross-section in Fig. 1. The concentric radiation shields/gap radiators are shown surrounding a telescope which we estimate can be as large as 1.7 m for the resources available for future Medium-size space missions. The telescope/radiator assembly is shown mated to the SOHO service module, which is the baseline bus designated for the mission.

Critical to the design of cold observatories in space is location: the further away from sources of heat, the longer the lifetime (for cryogenic observatories such as ISO or SIRTF) or the lower the equilibrium temperature (for radiatively-cooled observatories such as COBE or *Edison*). our baseline location is a halo orbit surrounding the L2 point, about 1.5 million km anti-sunward from the Earth, which is energetically relatively easy to enter. At this location, Earth contributes almost nothing to the spacecraft heat load. The equilibrium optical system temperature calculated for the design shown in Fig. 1 at L2 is about 30 K, which means that *Edison* will be limited in sensitivity by the celestial thermal noise at all wavelengths shortward of about 30 μm. At far-infrared wavelengths, broadband observations will be limited ultimately by source confusion, which requires a large aperture for increased sensitivity. Consequently, for broadband observations of point sources, *Edison* is the most sensitive infrared observatory under consideration by the space agencies. Operation at L2 also allows alternative spacecraft designs, in particular taking advantage of having the dominant heat source (the Sun) constantly on one side of the satellite. In the first place, the sun shield/solar array assembly, which could take advantage of recent developments in inflatable structure technology, would be

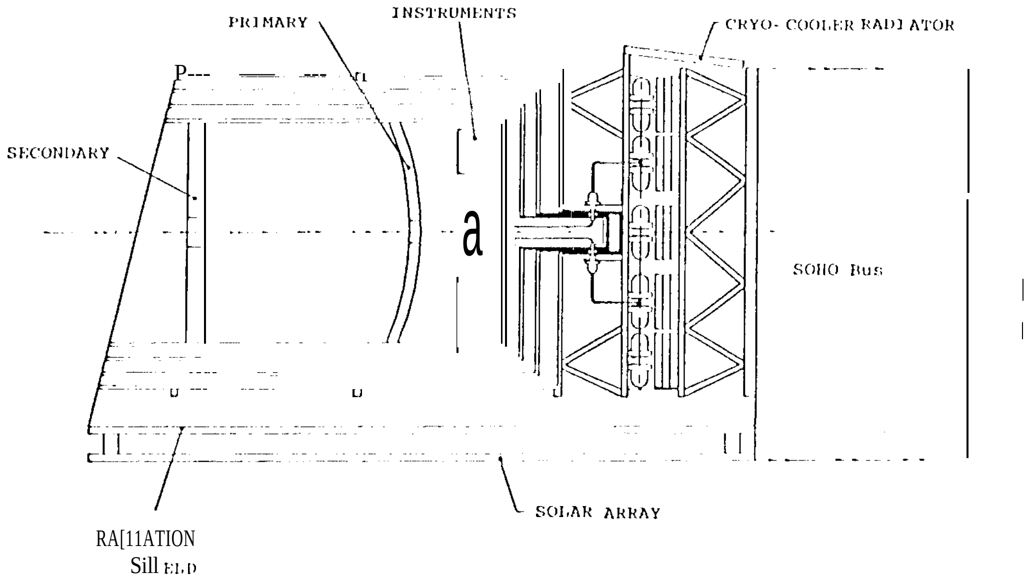

Fig. 1. Cross-sectional diagram of our current design for the *Edison* infrared space observatory, drawn approximately to scale, where the telescope primary is 1.7 m in diameter. The solar array panel and exterior sunshield are shown stored along the bottom of the figure. In this design, a set of 5 closed-cycle refrigerators are mounted along the top of the service module. In practice, the coolers will be enclosed. This present design has adopted the SOHO bus as the baseline service module.

on one side of the spacecraft, while the other will be exposed only to cold space. Taking advantage of this, Hawarden et al. (1992) described a schematic design in which large anti-sunward sections of the concentric radiation shields are removed, significantly increasing the radiating area. Recent estimates of the achievable temperature for such designs are in the range of 15 20 K. Furthermore, such estimates may be conservative, as

near-future performance of mechanical cooling systems under development at Rutherford Appleton Laboratory (RAL), JPL, and elsewhere allow significant additional cooling power beyond that possible via radiation alone.

2.3. CURRENT STATUS OF THE *Edison* PROJECT

The *Edison* infrared space observatory has been proposed to the European Space Agency (ESA) for Assessment/Phase A study in response to that agency's M3 opportunity. A parallel and supporting proposal to investigate the enabling technology has been submitted to NASA, The results of the ESA Assessment/Phase A are expected to be released in Spring 1996, with an expected M3 launch date of 2003.

Near-future work on the project includes [1] an advanced, detailed thermal model of our baseline design, as well as models for innovative geometries; [2] an advanced optical systems design and analysis; [3] continuing assessment and preliminary design on the cryo-coolers; and [4] an increasingly detailed and complete model for the limits to sensitivities for IR/Sub-mm observations.

2.4. *Edison*: THE NEXT STEP TO FUTURE IR OBSERVATORIES

Although *Edison* as proposed will be the most sensitive space telescope operating throughout most of the infrared, far-future telescopes in space will be expected to perform even better. Two technological directions seem attractive based upon presentations at this workshop: [1] increasing aperture, thus permitting major gains in raw sensitivity, and [2] spatial interferometry from orbit or on the moon. In the former case, radiative cooling of large volumes of the future observatory will be required to achieve low temperatures while allowing large light-collecting optics. Presumably, just as with *Edison*, segments of future IR space observatories will use additional onboard cryo-cooling systems. For the latter case, that of spatial interferometry, *Edison* may be considered as a prototype for one element of an array of space-based IR telescopes. Just as on Earth, interferometry is unsurpassed for resolving small-scale structure, which presumably will be required for study of material surrounding distant stars and to probe deeply into crowded fields. To achieve reasonable sensitivities, individual elements of interferometers will require as large light-collecting apertures as is feasible. This, in turn, requires radiatively-cooled designs.

In sum, *Edison* may properly be thought of as the first step in the direction of future space observatories working at infrared and sub millimeter wavelengths.

3. Investigation of Extra-Solar Planetary Material

3.1. *Edison* AND THE STUDY OF OUR SOLAR SYSTEM

One major program for *Edison* will, of course, be the study of our own planetary system (Encrenaz 1992). Within the next few years, ESA's *Infrared Space Observatory* (ISO) satellite and within a decade, NASA's *Space Infrared Telescope Facility* (SIRTF), will be able to produce a complete spectral atlas of the outer planets, which should be a major step forward in the studies of, for example, the chemical evolution of planetary atmospheres and surface compositions. However, the angular resolution and lifetime of both facilities will be a serious limitation to such programs as study of the spatia variations in atmospheric chemistry or the opportunity to study more than the few comets likely to enter the inner Solar System during the lifetime of a cryogenic mission.

Edison, in contrast, will not be so limited. As one example, the pointing constraints of cryogenic observatories are very severe: a glancing view of the sun is likely to significantly reduce the mission lifetime as liquid helium would rapidly boil away. A radiatively-cooled observatory should also be pointed away from heat sources, bu a brief view of the sun may do no more han heat large areas of the optical system. This almost certainly means a significant reduction in sensitivity due to the consequent high background and significant hermal gradients within the system may create serious mechanical stress. However, both may be manageable and, in any case, it is unlikely that mission duration would be affected. If this is the case, it may be feasible to deliberately observe with *Edison* close to the sun, obtaining detailed infrared spectra of Venus, for example, or of comets during their most chemically active phases. The possibility of such observations will have to be considered and modeled carefully during the development phase of this space observatory.

3.2. DETECTION O. EXTRA-SOLAR PLANETS?

The *Edison* observatory would appear in the title of these conference proceedings, rather than being discussed in one of many papers, were we able to demonstrate unambiguously that this space observatory would be able to detect reasonably normal planets around neighboring stars. With an aperture of about 1.7 m, *Edison* certainly has the sensitivity to detect planets such as Jupiter or the Earth out to distances of a few parsecs, given integration times of many hours. However, detection of such planets also requires the ability 10 discriminate between the feeble emission of the planet from that of the central star. This appears to require an optical system with a baseline or an aperture at least a few times larger than that which we are proposing for *Edison*. Some estimate of the required aperture for detection may be found, for example, in the work of Rapp (1992, 1993). The agglomeration of circumstellar heavy elements into planets makes life close to stars possible, but at the same time significantly reduces the infrared signatures that indicate the presence of solid state material. Dusty disks and shells surrounding stars are easier to detect and study than are planets. Consequently, it will be more fruitful in the near future to search for dusty material around more-or-less normal stars, than it will be to search for the evidence of planets. In any case, so far as we can surmise, planets form out of dusty circumstellar material, so that studies of dusty material around young stars will be critical to a complete understanding of the evolutionary process for planets. One intriguing result is the interpretation by Marsh and Mahoney (1992, 1993) of depressions in the mid-infrared spectra of T Tauri stars as being due to "gaps" in the circumstellar material. These gaps, if real, are suggested to be the result of missing material in a dusty circumstellar disk. Such missing matter could be the result of gravitational perturbation by one or more sill)-stcl]ar bodies. If this interpretation is correct, the technique of Marsh and Mahoney may be profitably applied to extremely large numbers of T '1'auri-like stars, surveying the creation of planets. If, that is, an observatory has sufficient sensitivity and powers of discrimination. *Edison* will have sufficient sensitivity to detect easily T Tauri objects with high signal-to-noise throughout the Milky Way. **At** a distance of about 140 pc, '1' Tauri has a 10 μm flux density of about 130 Jy. *Edison*'s *10* μm sensitivity as a function of integration time is approximately F_ν (mJy) $\sim 0.1\,[\frac{\lambda}{\Delta\lambda}]^{\frac{1}{2}}\,[\frac{S}{N}]\,t^{-\frac{1}{2}}$ in the plane of the Milky Way (Thronson et al. 1993), where the right side of the expression includes an adopted spectral resolution and desired signal-to noise ratio. A spectral resolution of 20 and a signal-to noise ratio of 1 () should be sufficient 10 determine whether or not dusty T Tauri objects possess depressions in their spectrum. A little algebra allows us to estimate that *Edison* could obtain observations sufficient to determine the presence of gaps in a dusty disk for objects at a distance of 30 kpc within a few seconds. In practice, the most likely limitation to this type of study will be source confusion in the plane of our galaxy and/or in crowded fields of young stellar clusters. As emphasized in the opening sections of this presentation, *Edison* has been specifically proposed to possess the largest aperture of any future IR space observatory, which will be of significant advantage for observations in confused fields. However, the plane of the Milky Way will still be a difficult region in which to work at the extreme sensitivities of which *Edison* is capable. Instead, it may be more profitable to study the formation of planets outside the Milky Way.

3.3. Planet Formation in Other Galaxies

It will be most interesting to identify the formation of planets around the nearest stars, thus demonstrating that our neighborhood in the cosmos is not devoid of life and, consequently, hopelessly boring. Moreover, planets around nearby stars are presumably being born under somewhat similar conditions to those which prevailed when our own Earth formed. Such observations would supply a key data point in our understanding of the Solar System's creation. However, observations of more distant objects will be necessary to achieve a complete picture of the process of planetary system creation. As noted in the previous section, detection of distant circumstellar material may be very difficult in the plane of our galaxy, due to the serious issue of source crowding. As a consequence, we suggest that study of T Tauri stars and related objects in Local Group galaxies may be easier and will certainly provide important information to a broad general picture of planet formation. Here we assume that the interpretation is correct of the depressions in mid-IR spectra from T Tauri stars as being due to perturbations by sub-stellar (planetary?) objects (Marsh and Mahoney 1992, 1993). Observations of planet-forming circumstellar material around T Tauri objects in other galaxies will be interesting for at least two reasons: [1] we hypothesize that planetary formation frequency, rate, planetary mass is dependent in some fundamental way upon the metallicity of the interstellar medium (ISM) out of which the stellar/planetary system formed; and [?] we hypothesize that planetary formation also depends upon the dynamics of the ISM: large-scale flows, compression waves, and/or shocks. These gross characteristics vary significantly from object to object in the Local Group. In addition, as noted already, due to source crowding, it may be easier to observe young stars in other galaxies than in our own.

In Fig. 2, we present the spectrum of T Tauri at the distance of the Large Magellanic Cloud (55 kpc), along with the expected sensitivity of *Edison* for a three-hour, low-resolution observation. This calculation includes the effects of confusion by distant background galaxies, but *not* the effects of confusion within the LMC itself, which could be severe: at 10 μm, *Edison* will have a diffraction-limited angular resolution of about 1.''7 or a spatial resolution of about 0.5 pc at the distance of the LMC. This may be larger than the separation between stars in young clusters.

In any case, *Edison* may be sensitive enough to survey the low-mass star-forming regions in the LMC for evidence of creation of planetary material. Comparison of such a census with a similar survey in the Milky Way will be a major step in understanding the gross galaxian parameters which govern the formation of planets. Furthermore, *Edison* has the theoretical sensitivity to detect an object such as T Tauri throughout a large fraction of the Local Group. After an integration time of 1 day (about 10^5 s), *Edison* will just about be able to obtain a low-resolution spectrum of an object such as T Tauri in the Andromeda Galaxy. This volume of space also includes a number of metal-poor, star-forming dwarf galaxies. Not only is stellar creation in these objects intrinsically interesting, but they also offer the opportunity to investigate formation of stars and planets under conditions which might roughly approximate that of the very early universe.

4. Summary

Edison has been proposed to the European Space Agency as a radiatively-cooled, large-aperture, long-lived infrared space observatory to follow the current generation of cryogenic missions. Current design is for a 1.7 m telescope to be launched by an Ariane 5, Proton, or Atlas. Preliminary thermal models indicate that it is straightforward to cool the optical system via radiation to temperatures of 30 K.

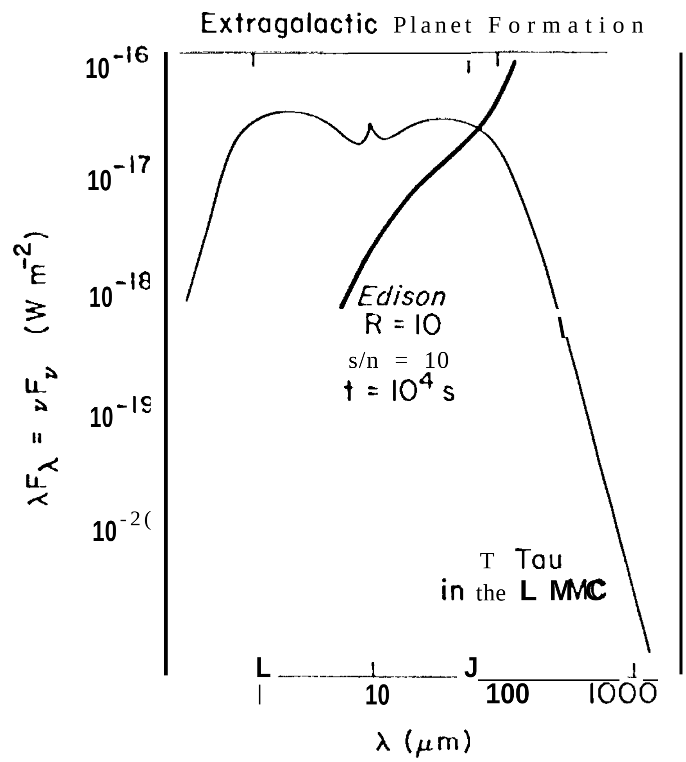

Fig. 2. It may be possible to detect planetary system formation in other galaxies with *Edison*. Here we show the spectrum of T Tauri if observed at the distance of the Large Magellanic Cloud (55 kpc), along with the expected sensitivity of *Edison* for a S/N = 10 detection with a spectral resolution of 10 after an integration time of about 3 hours. The calculated sensitivity does not include the effects of source confusion within the LMC.

Improved thermal design and/or the use of near-future cryo-coolers may allow temperatures as low as '20 K.

A large-aperture infrared telescope operating at the celestial background in space will allow sensitive investigations into a wide range of scientific programs related to extra-solar planetary material, including studying the composition of circumstellar disks throughout much of the Milky Way, high-resolution spectroscopy of brown dwarf atmospheres, and low-resolution spectroscopy of T Tauri stars as part of a search for extragalactic planet formation. NASA has also been requested to participate with ESA at least in the early stages of the assessment of the *Edison* project, with the possibility of formal partnership with ESA at a future date.

Acknowledgements

This work was supported in part by NASA Grant NAG 8-899, Rutherford Appleton Laboratory (RAL), and the Royal Observatory, Edinburgh. We appreciate the support of the *Edison* Study Office at RAL, where current design work is taking place.

References

Encrenaz, T.: 1992, *Sp Sci Rev* **61**, 13

Hawarden, T. G., Cummings, R. o., Telesco, C. M., and Thronson, H. A.: 1992, *Sp Sci Rev* G], 113

Marsh, K. A. and Mahoney, M. J.: 1992, *Ap J* **395**, L115

Marsh, K. A. and Mahoney, M. J.: 1993, *ApJ Lett*, in press

Rapp, D.: 1992, 'Potential for Active Structures Technology to Enable Lightweight Passively Cooled IR Telescopes', *JPL Internal Report* D-9449,

Thronson, H. A. et al.: 1992, *Sp Sci Rev* **61**, 145

Thronson, H. A., Rapp, D., Bailey, B. and Hawarden, T. G.: 1993, *PASP*, submitted

Werner, M. W.: 1993, in SIRTF Surveys, ed(s)., *Sky Surveys: 1'7010s1.1.7 to Protogalaxies*, Cd., B. T. Soifer, Astronomical Society of the Pacific: San Francisco, in press.